Microwave Assisted Convective Drying Characteristics of Elephant Foot Yam

F. M. Sahu, Parth Pandit

***Abstract*— Elephant Foot Yam was blanched at 80°C for 4 min in hot water and exposed to microwave treatment under different microwave power ranging from 300 W to 900 W and exposure time (1, 1.5 and 2 min) and then dried in convective dryer at 60°C to study their effect on microwave assisted convective drying characteristics. Drying time, average drying rate, effective moisture diffusivity, activation energy and rehydration ratio were various factors studied. Increased in microwave power and exposure time increased drying rate and decreased the drying time. The whole drying took place in falling rate period only. Midilli *et al*. model was found to describe the drying behaviour of elephant foot yam most precisely (highest R^2 = 0.9996; least RMSE = 0.0051). The effective moisture diffusivity values ranges from 4.2 × 10^{-10} to 1.1× 10^{-9} m^2/s and activation energy from 3.14 to 4.48 W/g. From storage study and sensory evaluation with quality in terms of protein, total sugar, ash and oxalate content was found to be acceptable in all drying treatments. Based on oxalate content and drying characteristics, exposure of 900 W microwaves for 2 min followed by hot air drying at 60°C was found to be most acceptable.**

***Index Terms*— Elephant Foot Yam, Exposure time, Microwave power, Oxalate content**

I. INTRODUCTION

Amorphophallus paeoniifolius (Densst.) Nicolson, commonly known as Elephant foot yam, is a highly potential tropical underground stem tuber rich in nutrients. It is a very good source of starch as well as protein and very popular as a vegetable in various Indian cuisines. Elephant foot yam belongs to family *Araceae*, is widely grown and consumed in south-east Asian countries like India, Philippines, Malaysia, and Indonesia and has great export potential since its commercial cultivation is not in many countries [1].

The tubers are used for preparing ayurvedic medicine as they are anti-inflammatory, anti-haemorrhoidal, astringent, haemostatic, digestive, appetizer, rejuvenating and tonic [1-17]. The plant starch is easily extractable and with good viscosity, stability and suitability for many applications in food industry [2]. Because of its higher yield potential, culinary, medicinal and therapeutic values, it is referred to as “King of Tuber Crops” [3].

Drying is a complex unit operation involving simultaneous heat and mass transfer, particularly under transient condition. It is one of the earliest method of increasing the storage life of perishable agricultural produce by decreasing its moisture content thus the growth of undesirable microorganism by reducing the water activity and extend its shelf life [4].

One of the most commonly used drying techniques was the convective hot air drying. During drying food materials are exposed to elevated temperatures, which lead to an increase in shrinkage and toughness, reduction of rehydration capacity of the dried product, and it also causes serious damage to flavour, colour, and nutrient content [5]. In common industrial dryers with hot air since the heat conduction is low the energy efficiency will decrease and more time is necessary for drying. In order to overcome these problems and reduce drying time to achieve an efficient and rapid heat transfer processes with preservation of quality, the use of microwave (MW) for drying have been considered.

In microwave processing the energy is transferred directly to the sample producing a volumetric heating [7-19]. This rapid internal energy generation causes the pressure build up and results in rapid evaporation of water [6]. Microwave drying is having advantage of high drying rates, reduced drying time, better product quality and efficient space utilization [8].

Enzymatic browning is the second largest cause of quality loss in fruits and vegetables. Since enzymatic browning causes deterioration of sensory and nutritional quality and affects appearance and organoleptic properties, inactivation of Polyphenol Oxidase (PPO) is desirable for preservation of foods [9]. Conventional hot water blanching of vegetables, widely used in industry, involves the immersion of the fresh product for a prescribed time into hot water kept at a constant temperature ranging from 70 to 100°C [10].

The rapid and volumetric heat generation of microwaves has been utilized to improve conventional drying processes. But strictly speaking, a stand- alone microwave drying does not exist. Microwaves are used to assist or enhance another drying operation. The most widely used is a combination of microwave heating with hot air drying [6-7].

Keeping the above points, the present investigation was carried out to use microwave heating in the beginning of drying to enhance the drying rate during convective drying of elephant foot yam, which could be significantly contributed to time and energy saving with quality product for food processing industry with following objectives:

- To optimise different blanching conditions and microwave power on drying kinetics of elephant foot yam.
- To evaluate quality characteristics of dried product.
- To select the model to describe the microwave drying behaviour of elephant foot yam.

II. MATERIALS AND METHODS

A. Sample Preparation

Fresh elephant foot yams were purchased from the local market at Navsari, Gujarat, India. Prior to treatment, the elephant foot yam were washed properly in clean tap water for

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removal of external impurities and peeled manually to remove the skin by using a stainless steel knife. Peeled elephant foot yams were then cut in to 10 mm thick slices of square shape of 30 mm × 30 mm size and samples of 500g were prepared for the experiment.

B. Blanching procedure

The samples (approximately 500g each) were then submitted to a blanching process in which the slices were placed in a metal basket in water baths containing 1.5 L of water previously heated to 80°C. Then, blanching was carried out for 2, 4 and 6 minutes. After blanching, the samples were cooled and the effects of blanching time on the activity of polyphenol oxidase (PPO) were evaluated. The activity of polyphenol oxidase (PPO) in elephant foot yam was determined by the spectrophotometric method proposed by Esterbaner *et al.* (1977) [11-18].

C. Microwave -assisted drying

Blanched slices of elephant foot yam were then heated in a microwave oven (Make: SAMSUNG, Model-CE1041DFB) at different power levels of 300, 600 and 900 W with different exposure time of 1, 1.5 and 2 minutes. Microwave heated elephant foot yam slices were then immediately transferred to hot air tray dryer for further drying at a constant temperature condition of 60°C up to a final moisture content of 10% (db).

D. Moisture content

Moisture content of fresh elephant foot yam was determined using method as described in AOAC (1990).

E. Drying rate

The drying rate during the experiments was calculated using the following formula.

$$\text{Rate of drying} = \frac{dM}{dt} = \frac{M_{t+dt} - M_t}{dt} \qquad (1)$$

Where,

M_t = moisture content at instant of time t.

M_{t+dt} = moisture content at time after an interval of dt

The overall drying rate was calculated as the ratio of difference of initial and final moisture content $(M_0 - M_f)$ and total drying time (t_T). The overall drying rate was calculated as follows.

$$\text{Overall drying rate} = \left(\frac{\partial M}{\partial t}\right) = \frac{M_0 - M_f}{t_T} \qquad (2)$$

F. Mathematical modeling of Drying Kinetics

Experimental moisture content data of elephant foot yam during microwave assisted convective drying were converted to dimensionless moisture ratio.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad (3)$$

Where,

MR = is the moisture ratio (dimensionless)

M_0 = is the initial moisture content

M_t = is the moisture content at time t

M_e = is the equilibrium moisture content

Equation (3) can further simplified to $MR = \frac{M_t}{M_0}$ as the values of M_e is relatively small compared to M_0 and M_t for long drying time, hence the error involved in the simplification by assuming that M_e is equal to zero is negligible. All moisture contents are denoted in dry basis (kg water/ kg dry matter).

The moisture ratio curve can better explain the drying behavior than that of the moisture content curve, as the initial was one in each experimental data irrespective of the initial moisture content if varies. The experimental data of these moisture ratios versus drying time were fitted to drying models to describe the drying behavior of elephant foot yam. The following three semi-empirical models were tested to describe the drying behavior of elephant foot yam.

(1) Generalized exponential model

$$MR = \frac{M_t}{M_0} = ae^{(-kt)} \qquad (4)$$

(2) Page's Model

$$MR = \frac{M_t}{M_0} = ae^{(-kt)^n} \qquad (5)$$

(3) Midilli *et al.*, Model

$$MR = \frac{M_t}{M_0} = ae^{(-kt)^n} + bt \qquad (6)$$

Where k and b are the drying constant (1/min); and a and n are dimensionless model parameters.

G. Effective moisture diffusivity

Fick's second law of diffusion equation, symbolized as a mass-diffusion equation for drying of agricultural products in a falling rate period, is shown in the following equation:

$$\frac{\partial M}{\partial t} = D_{eff} \cdot \frac{\partial^2 M}{\partial x^2} \qquad (7)$$

By using appropriate initial and boundary conditions, the analytical solutions [12-20] for various geometries and the solution for infinite slab object with constant diffusivity is given as:

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-(2n+1)^2\pi^2\frac{D_{eff}.t}{L^2}\right) \qquad (8)$$

Where, D_{eff} is the effective diffusivity (m^2/s); L is the thickness of samples (m); t is the drying time (s) and n is a positive integer.

Equation (8) can be simplified by taking the first term only

$$MR = \frac{8}{\pi^2}\exp\left(-\pi^2\frac{D_{eff}.t}{L^2}\right) \qquad (9)$$

Equation (9) is evaluated numerically for Fourier number, $F_0 = D_{eff} \times t/L^2$, for diffusion and can be rewritten as:

$$MR = \frac{8}{\pi^2}\exp\left(-\pi^2 F_0\right) \qquad (10)$$

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) + \left(-\pi^2 F_0\right) \quad (11)$$

Thus: $F_0 = 0.101\ln(MR) - 0.0213$ (12)

The effective moisture diffusivity was calculated using following equation as:

$$D_{eff} = \frac{F_0}{\left(-\frac{t}{L^2}\right)} \quad (13)$$

The effective moisture diffusivity (D_{eff}) was estimated by substituting the positive values of (F_0) and the drying time along with the thickness of sample (L) for each corresponding moisture contents under different drying conditions. The average moisture diffusion coefficients were typically determined by plotting experimental drying data in terms of $\ln(MR)$ versus drying time (t), because the plot gives a straight line with a slope as $\left(\pi^2 \frac{D_{eff}}{L^2}\right)$.

H. Activation Energy:

The correlation between the drying conditions and the values of the effective diffusivity using Arrhenius type [13] equation is given by

$$D = D_0 \exp\left(-\frac{E_a}{RT_{abs}}\right) \quad (14)$$

Where, D_0 = diffusion coefficient; E_a = activation energy (kJ/mol); R = universal gas constant (8.314 J/(mol.K)); and T_{abs} = absolute temperature (K).

In as much as temperature is not precisely measurable inside the microwave oven, the activation energy for microwave assisted drying is found as modified from the revised Arrhenius equation. In this method it is assumed as related to effective moisture diffusion and the ratio of microwave output power to sample weight (m/P) instead of air temperature. Equation (14) can then be effectively used as follows:

$$D_{eff} = D_0 \exp\left(-\frac{E_a m}{P}\right) \quad (15)$$

Where, E_a is the activation energy (W/g), m is the mass of raw sample (g), D_0 is the pre-exponential factor (m^2/s) and P is the microwave power (W).

I. Rehydration ratio:

Dried elephant foot yam slices were rehydrated by immersing in warm water (about 60°C) at room temperature. About 5g of dried samples were placed in glass beakers containing water in ratio 1:25 (w/w) for 8 hr. Samples were drained, blotted with tissue paper and weighed. The rehydration capacity was calculated as follows.

$$\text{Rehydration ratio} = \frac{W_r}{W_d} \quad (16)$$

Where,

W_r is the rehydrated weight, g

W_d is the dehydrated weight, g

J. Statistical analysis of drying kinetics

Curve expert (version 1.4) software (Microsoft Corporation, Mississippi, USA) was used to fit the mathematical models to experimental data. Two comparative indices were used as goodness and to select the best model such as:

(1) coefficient of determination (R^2) and

(2) the root mean square error (RMSE)

These indices are as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)}{\sum_{k=1}^{N}\left(MR_{pre,i} - \frac{\sum_{k=1}^{N} MR_{pre,i}}{N}\right)} \quad (17)$$

and

$$RSME = \left[\frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N}\right]^{\frac{1}{2}} \quad (18)$$

Where,

$MR_{exp,i}$ = experimental moisture ratio of i^{th} data

$MR_{pre,i}$ = predicted moisture ratio of i^{th} data

N = number of observations

The model is said to be good if R^2 value is high and RMSE value is low.

K. Quality Analysis

For quality analysis after drying and storage studies following methods were adopted. Protein content by Lowry's method (1951)[13]; Total Ash Content, Total Sugar Content and Sensory evaluation by Ranganna (1990)[14]; Oxalate content by Abaza *et al.* (1968)[15].

III. Results and Discussion

A. Influence of blanching time on the enzyme activity

In the experiment blanching treatments using water bath (80°C) was conducted on elephant foot yam slices and the variation of PPO activities with blanching time (2, 4 and 6 minutes) during the blanching process was measured in replication of seven and the average values were presented in Fig. 1.

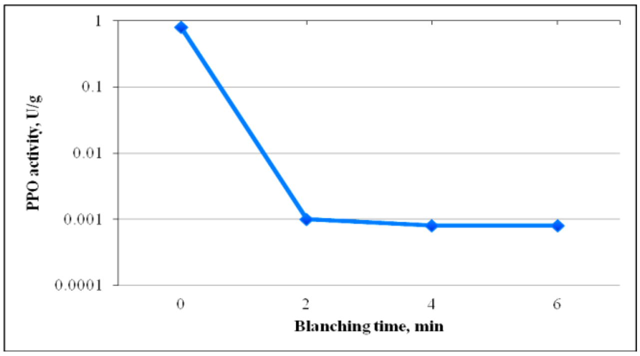

Fig. 1 Influence of blanching time on the enzyme activity

From the Fig. 1, it can be concluded that the PPO activity was decreased as the blanching time increased in all three treatments. The maximum and minimum values for PPO activity were observed in T_1 (2 min) and T_2 (4 min) as 0.0010 U/g and 0.0008U/g respectively. Treatments T_2 and T_3 are at par with each other.

B. Effect on moisture content

The average initial moisture content of elephant foot yam were found to be 395.05 % db (3.9505 kg H_2O/ kg dry matter) and the final moisture content of elephant foot yam after drying in different treatments were found to be 9.9 % db (0.099 kg H_2O/ kg dry matter). The moisture content (kg H_2O/ kg dry matter) vs. drying time (min) were plotted and shown in Fig. 2. From the figure it can be concluded that the decrease in moisture content was faster during initial period of drying and the reduction in moisture content was found to be slower during the later part of drying. Reduction in moisture content was very less in last few hours of drying.

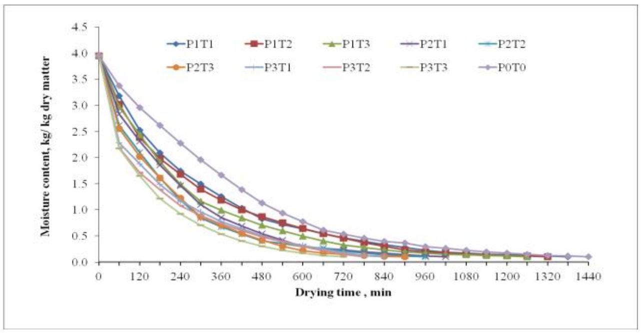

Fig. 2 Variation of moisture content with drying time for different drying treatments

C. Effect on drying time

From the Fig. 2, it can also be seen that the minimum value for drying time was noted to be 720 minutes for the treatment P_3T_3 and maximum value was 1440 minutes for the treatment P_0T_0 (Without microwave heating, only hot air drying at 60°C). This result indicated that mass transfer within the sample was more rapidly during higher microwave power heating because more heat was generated within the sample creating a large vapour pressure difference between the center and the surface of the product due to characteristics microwave volumetric heating. It can be seen that the decrease in moisture content with drying time was remarkable during the period of microwave heating and then slowly decreasing with time.

D. Effect on drying rate

The variation of dying rate ((kg H_2O/kg dry matter)/min) vs. drying time (min) of elephant foot yam were shown in Figure 3 to 6. From the Fig. 3 to 6 it can be seen that maximum overall drying rate was observed in treatment P_3T_3 which was noted to be 0.0535 ((kg H_2O/kg dry matter)/min) and the lowest value of drying rate among the treatments was noted to be 0.00267 ((kg H_2O/kg dry matter)/min) for the treatment P_0T_0 (Convective tray drying @ 60°C). There was no constant rate drying period in the present investigation. Whole drying process took place in falling rate period of drying process for all treatments. Initially there was sudden increase in drying rate and later on the drying rate decrease with decreasing

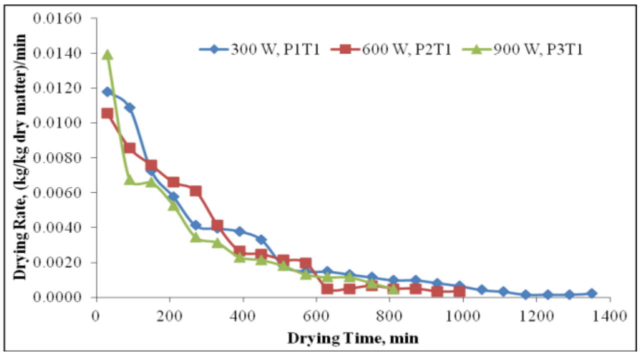

Fig. 3 Variation of drying rate with drying time at different MW power levels for 1 min exposure time

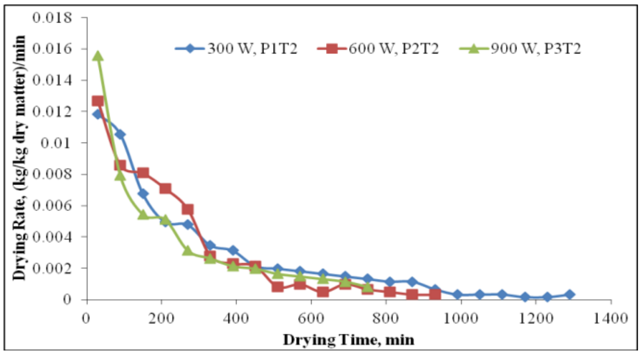

Fig. 4 Variation of drying rate with drying time at different MW power levels for 1.5 min exposure time

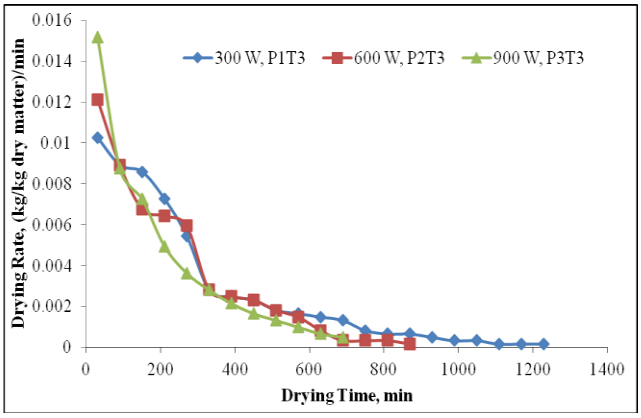

Fig. 5 Variation of drying rate with drying time at different MW power levels for 2 min exposure time

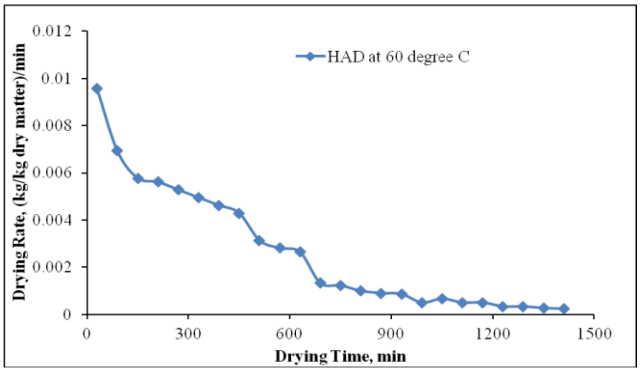

Fig. 6 Variation of drying rate with drying time for hot air drying at 60°C

moisture content and increasing drying time. The result of microwave assisted drying showed that increasing microwave power level increased the drying rate.

E. Validation of semi-empirical mathematical models for drying kinetics.

Drying curves of moisture ratio vs. drying time reflecting the effect of microwave power and sample thickness where shown in Fig. 7. From the figure it can be seen that drying time was inversely proportional to microwave power and exposure time.

The moisture ratio vs. drying time curve can better explain a drying behaviour than moisture content vs. drying time curve as the initial value was one in each experimental data irrespective of the initial moisture content. To describe the effect of microwave power and exposure time on drying kinetics of elephant foot yam, three semi-empirical thin layer drying models such as Generalize Exponential model, Page's model and Midilli *et al.* model were used. The moisture ratio and drying time data were fitted to this three drying models.

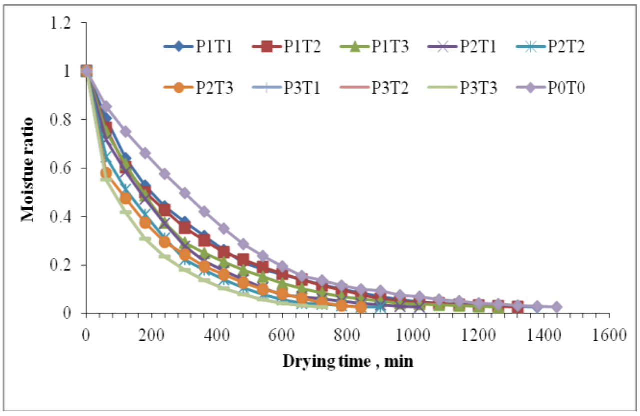

Fig. 7 Variation of moisture ratio with drying time for different drying treatments

All three models were adequate to describe the microwave assisted drying characteristics of elephant foot yam since lowest R^2 value and highest RMSE were found to be 0.9618 and 0.0545 respectively, (treatment P_3T_2, Generalize exponential model) that is adequacy of $R^2 > 90$ % is fulfilled by all models. The experimental moisture ratio and predicted moisture ratio vs. drying time curve fitting for treatment P_3T_3 in different models were shown in Fig. 8 to 10.

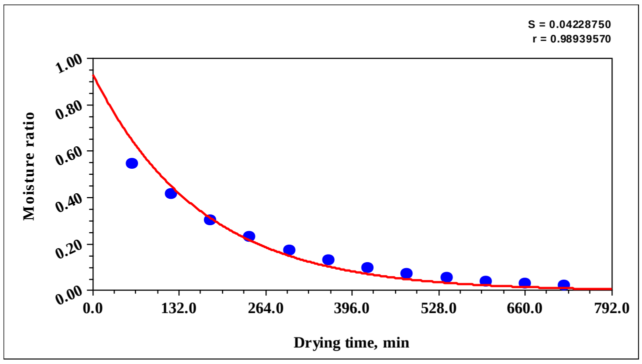

Fig. 8 Comparison of experimental and predicted moisture ratio vs. drying time of elephant foot yam by Generalized exponential model for treatment P_3T_3

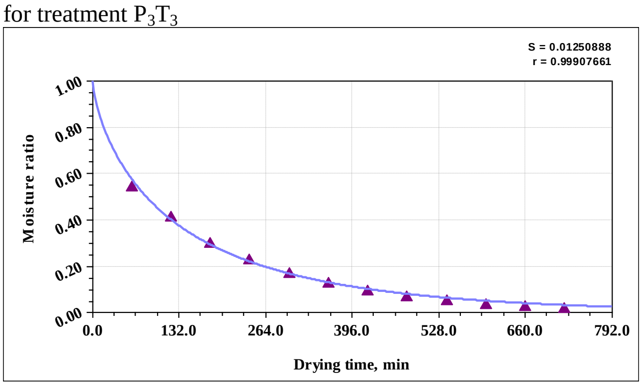

Fig. 9 Comparison of experimental and predicted moisture ratio vs. drying time of elephant foot yam by Page's model for treatment P_3T_3

Curve fitting of experimental data was performed using nonlinear regression analysis of *Curve Expert (version 1.4)*. Comparative indices for statistical model parameters and coefficient of models for MW assisted drying of elephant foot yam were represented in Table 1 and Table 2, respectively. The highest value of R^2 (0.9996) and lowest value of RMSE (0.0051) observed for treatment P_3T_2 with Middli *et al.* model.

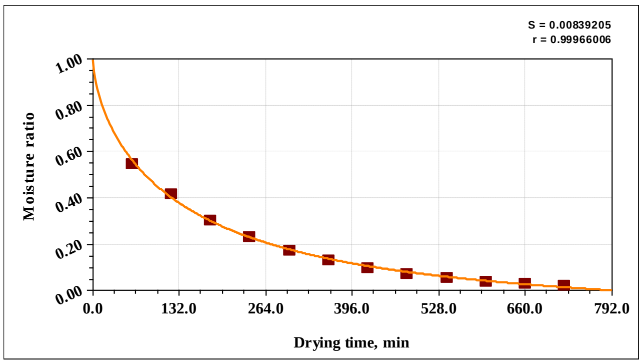

Fig. 10 Comparison of experimental and predicted moisture ratio vs. drying time of elephant foot yam by Midilli *et al.* model for treatment P_3T_3

F. Effect on Effective moisture diffusivity

Variation in effective moisture diffusivity of elephant foot yam with moisture content at different microwave power levels is shown in Table 3. Effective moisture diffusivity

values of elephant foot yam under various drying conditions were estimated in the range of 8.2×10^{-11} to 1.1×10^{-9} m^2/s. The highest effective moisture diffusivity was observed under the treatment in P_3T_3 (1.1×10^{-9} m^2/s), followed by the treatment of P_3T_2 (7.5×10^{-10} m^2/s). The lowest value of effective moisture diffusivity was observed in treatment P_0T_0 (8.2×10^{-11} m^2/s), followed by the treatment of P_1T_1 (4.2×10^{-10} m^2/s). The effective moisture diffusivity increased with increase in microwave power and exposure time. However, the moisture diffusivity further was higher at any level of moisture content at higher microwave power level, resulting into shorter drying time.

TABLE I Comparative indices of statistical models parameters for microwave assisted drying of elephant foot yam

Treatments	Drying conditions		Generalized Exponential Model $MR = ae^{-(kt)}$		Page's model $MR = e^{-(kt^n)}$		Midilli *et al.*, model $MR = ae^{-(kt^n)} + bt$			
	MW power, W	**MW exposure time, min**	**a**	**k**	**k**	**n**	**k**	**n**	**a**	**b**
P_1T_1	300	1.0	0.9670	0.0031	0.0060	0.8950	0.0058	0.9010	1.0020	0.000003
P_1T_2	300	1.5	0.9420	0.0031	0.0086	0.8410	0.0098	0.8170	1.0000	-0.000010
P_1T_3	300	2.0	0.9630	0.0036	0.0079	0.8730	0.0070	0.8980	1.0000	0.000010
P_2T_1	600	1.0	0.9710	0.0041	0.0069	0.9150	0.0063	0.9290	0.9910	0.000003
P_2T_2	600	1.5	0.9560	0.0048	0.0012	0.8420	0.0106	0.8660	0.9950	0.000010
P_2T_3	600	2.0	0.9510	0.0048	0.0120	0.8440	0.0136	0.8170	0.9940	-0.000019
P_3T_1	900	1.0	0.9060	0.0046	0.0259	0.7090	0.0434	0.5980	0.9980	-0.000087
P_3T_2	900	1.5	0.8980	0.0049	0.0350	0.6640	0.0623	0.5390	0.9990	-0.000109
P_3T_3	900	2.0	0.9330	0.0061	0.0281	0.7260	0.0379	0.6590	0.9990	-0.000052
P_0T_0	No MW*, only HAD#		1.0210	0.0026	0.0015	1.0880	0.0010	1.1490	0.9830	0.000011

*MW = Microwave and #HAD = Hot Air Drying

TABLE II Coefficients of drying model for microwave assisted drying of elephant foot yam

Treatments	Drying conditions		Generalized Exponential Model $MR = ae^{-(kt)}$		Page's model $MR = e^{-(kt^n)}$		Midilli *et al.*, model $MR = ae^{-(kt^n)} + bt$	
	MW power, W	**MW exposure time, min**	**R^2**	**RMSE**	**R^2**	**RMSE**	**R^2**	**RMSE**
P_1T_1	300	1.0	0.9970	0.0147	0.9996	0.0055	0.9996	0.0054
P_1T_2	300	1.5	0.9936	0.0212	0.9993	0.0070	0.9995	0.0060
P_1T_3	300	2.0	0.9953	0.0186	0.9989	0.0087	0.9992	0.0078
P_2T_1	600	1.0	0.9972	0.0150	0.9984	0.0117	0.9984	0.0123
P_2T_2	600	1.5	0.9928	0.0240	0.9978	0.0128	0.9980	0.0134
P_2T_3	600	2.0	0.9928	0.0244	0.9974	0.0148	0.9978	0.0146
P_3T_1	900	1.0	0.9726	0.0458	0.9952	0.0188	0.9988	0.0104
P_3T_2	900	1.5	0.9618	0.0545	0.9958	0.0180	0.9996	0.0051
P_3T_3	900	2.0	0.9789	0.0420	0.9982	0.0125	0.9994	0.0084
P_0T_0	No MW, only HAD		0.9970	0.0162	0.9984	0.0012	0.9988	0.0105

G. Effect on activation energy

Variation in activation energy of elephant foot yam with moisture content at different microwave power levels is shown in Table 3. Highest activation energy was observed under the treatment P_1T_1 was noted to be 4.48 W/g, followed by the treatment of P_1T_2 with 4.34 W/g. The lowest value of activation energy among the treatments was noted to 3.14 W/g for the treatment P_3T_3. Activation energy for hot air drying of elephant foot yam (treatment P_0T_0) was noted as 56.35 kJ/ mol.

H. Effect of MW power (P) and exposure time (T) on protein content % (wb)

The data recorded on protein content as influenced by MW assisted drying was graphically illustrated in Fig. 11. The data pertaining to protein content % (wb) levels of dried elephant foot yam showed decreasing trend with increasing microwave power level and microwave exposure time. The decreasing trend also found during storage period of 6 months. Initially (0 day) the maximum protein content (1.51 % wb) was recorded in P_1T_1 treatment and was at par with P_1T_2 (1.47 % wb).

TABLE 3 Effective moisture diffusivity and activation energy at experimental drying conditions

Treatment	Effective moisture diffusivity (m^2/s)	Activation energy (W/g)
P_1T_1	4.2×10^{-10}	4.48
P_1T_2	4.4×10^{-10}	4.34
P_1T_3	4.9×10^{-10}	4.24
P_2T_1	5.7×10^{-10}	3.79
P_2T_2	6.5×10^{-10}	3.65
P_2T_3	6.9×10^{-10}	3.58
P_3T_1	6.9×10^{-10}	3.479
P_3T_2	7.5×10^{-10}	3.416
P_3T_3	1.1×10^{-9}	3.14
P_0T_0	8.2×10^{-11}	56.3 kJ/mol

However, the protein content (1.06 % wb) was recorded in treatment P_3T_3, which is minimum, when the dried elephant foot yam slices were subjected to storage for a period of 6 months. Similar decreasing trend was also observed at all the levels of storage durations.

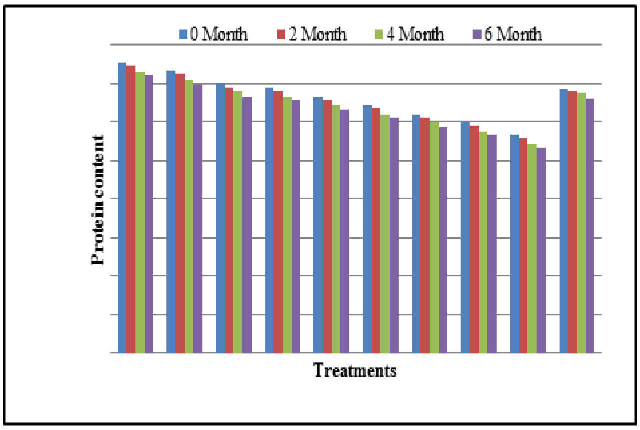

Fig. 11 Effect of microwave power and exposure time on protein content % (wb) of dehydrated elephant foot yam during storages

I. Effect of MW power (P) and exposure time (T) on total sugar content % (wb)

The data recorded on total sugar content as influenced by MW assisted drying treatments was graphically illustrated in Fig. 12. The data pertaining to total sugar content % (wb) levels of dried elephant foot yam showed decreasing trend as microwave power level and microwave exposure time increasing. The decreasing trend also found during storage period. Initially the maximum total sugar content (2.40% wb) was recorded in P_1T_1 treatment which was at par with P_1T_2 (2.37 % wb), P_1T_3 (2.35% wb) and P_2T_1 (2.33% wb). In 2^{nd} month of storage, treatment P_1T_1 (2.37 % wb) was at par with P_1T_2 (2.34 % wb). However, the least total sugar content (2.18 % wb) was recorded in treatment P_3T_3 when the dried elephant foot yam slices were subjected to storage for a period of 6 months. Similar decreasing trend was also observed at all the levels of storage duration. The variation in sugar content may be due to the partial break down of starch in presence of microwave energy.

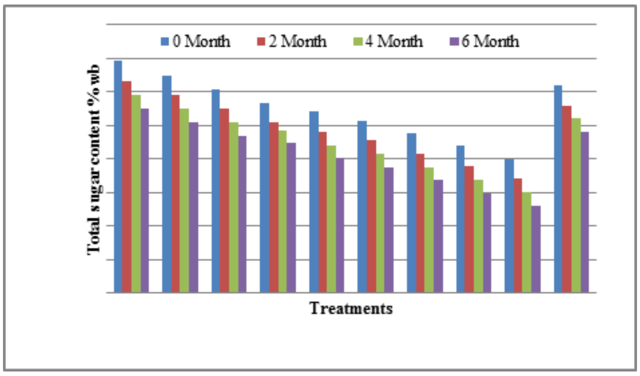

Fig 12. Effect of microwave power and exposure time on total sugar content % (wb) of dehydrated elephant foot yam during storage

J. Effect of MW power (P) and exposure time (T) on total ash content:

The data recorded on total ash content as influenced by MW assisted drying treatments was graphically illustrated in Fig. 13. The data pertaining to total ash content % levels of dried elephant foot yam showed increasing trend with increasing MW power level and MW exposure time and insignificant during whole storage period. Initially the maximum total ash content (5.58 %) which was at par with treatment P_3T_1 (5.53 %), P_3T_2 (5.54 %), and P_0T_0 (5.53 %). However, the least total ash content was recorded in treatment P_1T_1 (5.07 %) when the dried elephant foot yam slices were subjected to store. Similar increasing trend was also observed at all levels of microwave power.

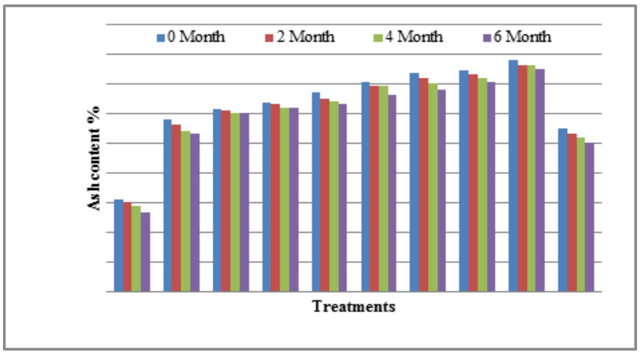

Fig. 13 Effect of microwave power and exposure time on ash content % (wb) of dehydrated elephant foot yam during storage

K. Effect of MW power (P) and exposure time (T) on Oxalate content

The data recorded on oxalate content as influenced by MW assisted drying treatments was graphically illustrated in Fig. 14 . The data pertaining to oxalate content % (db) levels of dried elephant foot yam showed decreasing trend during storage period. Initially the maximum oxalate content 0.212 % (db) was recorded in P_1T_1 treatment which was followed by P_1T_2 0.200 % (db). However, the least oxalate content (0.111 % db) was recorded in treatment P_3T_3 when the dried elephant foot yam slices were subjected to store. All treatments were at par with each other. Similar trend was also observed at all the levels of storage intervals. Microwave causes an acute heat stress which completely destroys the total oxalate.

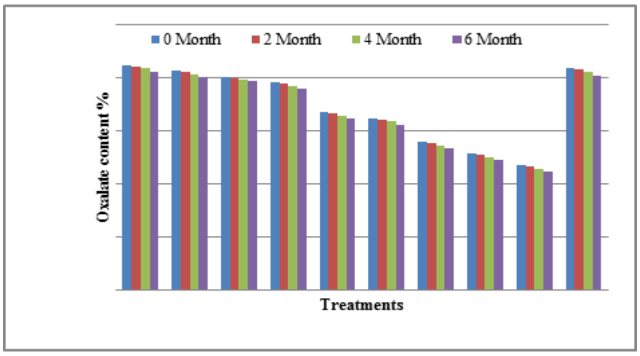

Fig. 14 Effect of microwave power and exposure time on oxalate content % (db) of dehydrated elephant foot yam during storage

L. Effect of MW power (P) and exposure time (T) on rehydration ratio:

The data recorded on rehydration ratio as influenced by MW assisted drying treatments was graphically illustrated in Fig. 15. The data pertaining to rehydration ratio of dried elephant foot yam chips showed an increasing trend with increasing microwave power level and microwave exposure time. But it showed a decreasing trend during storage period. Initially (0 day) maximum rehydration ratio was recorded in P_3T_3 (2.94) treatment which was followed by P_3T_2 (2.93). However, the least rehydration ratio was recorded in treatment P_0T_0 (2.11) when the dried elephant foot yam slices were subjected to storage period of 6 months. All treatments were at par with each other. Similar decreasing trend was observed at all the levels of storage intervals

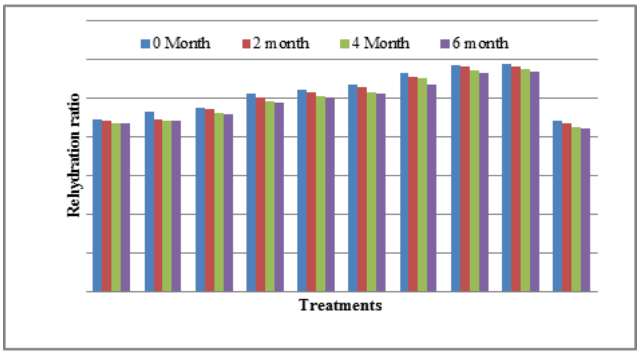

Fig. 15 Effect of microwave power and exposure time on rehydration ratio of dehydrated elephant foot yam during storage

M. Organoleptic quality attributes

Organoleptic quality attributes like colour, texture and overall acceptability of dehydrated as well as rehydrated elephant foot yam, was evaluated by panel of judges at 0 to 6 months of storage at 2 months interval during the experimentation and results of sensory evaluation. The overall acceptability score (out of 9 points) of dehydrated as well as rehydrated elephant foot yam best on colour and texture by various treatments during the storage period were depicted in Fig. 16.

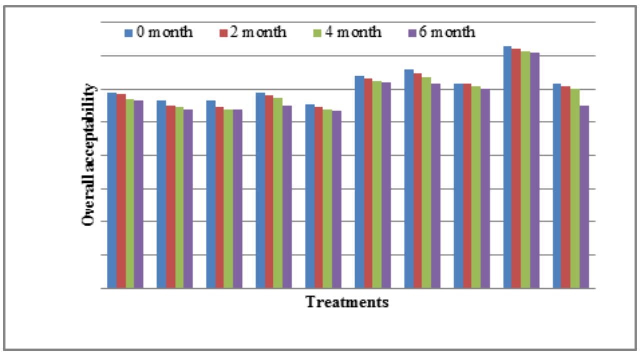

Fig. 16 Effect of microwave power and exposure time on overall acceptability of dehydrated and rehydrated elephant foot yam during storage

Panels of judges preferred the colour and texture score (7.28) of dehydrated as well as rehydrated elephant foot yam in treatment P_3T_3. Due to higher MW power level, puffing was developed in elephant foot yams which provide more porous structure. Therefore rehydration characteristic of MW assisted elephant foot yam were improved.

IV. Conclusion

On the basis of experimental results and data analysis following conclusion can be drawn.

1. Hot water blanching at 80°C for 4 min significantly decreased the PPO activity and stopped initiation of browning.
2. Increased in MW power and exposure time, increased the drying rate and decreased the drying time.
3. The whole drying process took place in falling rate period only and the average drying rate increased with increased MW power and exposure time.
4. Midilli *et al*. model was found to describe the drying behaviours of elephant foot yam most precisely as R^2 was highest (0.9996) as well as least RMSE (0.0051) as compared to other models.
5. Effective diffusivity ($4.2 \times 10^{-10} - 1.1\times 10^{-9}$ m^2/s) increased with increasing MW power and exposure time while activation energy (4.48 – 3.14 W/g) decreased with increasing MW power and exposure time.
6. Rehydration ratio increased with MW power and exposure time. MW power has significant effect on it.
7. Product quality in term of protein, total sugar, ash and oxalate content was found to be acceptable in all microwave assisted drying treatments.
8. Based on oxalate content and drying characteristics, treatments with microwave power of 900 W and exposure time of 2 min followed by hot air drying at 60°C was found to be most acceptable.
9. Experiment concluded that elephant foot yam slices should be blanched at 80°C for 4 min in hot water and dried with microwave power of 900 W for 2 min exposure time followed by hot air drying at 60°C to produce best quality dehydrated elephant foot yam.

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REFERENCES

[1] R. S. Misra, T. M. Shivlingaswamy, and S. K Maheshwari, "Improved production technology for commercial and seed crops of elephant foot yam", *Journal of Root Crops*. Vol. 27, 2001, pp. 197-201.
[2] S. N. Moorthy, "*Tuber crop starches*", Sreekariyam, Thiruvananthapuram, Kerala, India, Central Tuber crops Research Institute, 1994, pp. 1- 40.
[3] S. Sengupta, B. M. Chowdhary, B. N. Singh, and R. N. Ray, "Status of elephant foot yam cultivation in Jharkhand", In: *National Seminar on Amorphophallus: Innovative Technologies.* Abstract Book, Status Papers and Extended Summary, 19-20 July 2008, Patna, Bihar, pp. 30-34.
[4] G. V. Barbosa-Canovas, and H. Vega-Mercado, "Dehydration of foods", Chapman & Hall, New York, 1996.
[5] M. Maskan, "Microwave/air and microwave finish drying of banana. Journal of Food Engineering", Vol. 44, 2000, pp. 71–78.
[6] H. Feng, Y. Yin, and J.Tang, "Microwave drying of food and agricultural materials: basics and heat and mass transfer modelling. *Food Engineering Review*, Vol. 4(2), 2012, pp. 89-106.
[7] M. E. C. Oliveira, and A. S. Franca, "Microwave heating of food-stuff. *Journal of Food Engineering*, Vol.53, 2002, pp. 347–359.
[8] A. Harish, B. S. Vivek, R. Sushma, J. Monisha, and T. P. Krishna Murthy, "Effect of microwave power and sample thickness on microwave drying kinetics elephant foot yam (*Amorphophallus paeoniifolius*)", American *Journal of Food Science and Technology*, Vol. 2(1), 2014, pp. 28-35.
[9] A. Samanta, S. Das, P. Bhattacharyya, and B. Bandyopadhyay, "Inhibition of polyphenol oxidase in banana, apple and mushroom by using different anti-browning agents under different conditions, *International Journal of Chemical Science*, Vol. 8(5), 2010, pp.550-558.
[10] P. J. Fellow, "Blanching- in food processing technology: principle and practice" London, UK, 1988, pp. 201-208.
[11] H. Esterbauer, E. Schwarzl, and M. Hay, "A rapid assay for catechol oxidase and lactase using 2-nitro-5-thiobenzoic acid, *Analytical Biochemistry*, Vol.77, 1997, pp.486-494.
[12] J. Crank, "The mathematics of diffusion" 2nd Ed., Clarendon Press, Oxford, UK. 1975.
[13] S. Karatas, "Determination of moisture diffusivity of lentil seeds during drying", *Drying Technology*, Vol. 51(1), 1997, pp. 183-199.
[14] O. H. Lowry, N. J. Rosebrough, A. L. Farr, and R. J. Randal, "Protein measurement with the folin phenol reagent", *Journal of Biological Chemistry,* Vol. 193, 1951, pp. 265-275.
[15] S. B. Ranganna, "Handbook of analysis and quality control for fruit and vegetable products", Tata McGraw-Hill Education Private limited, New Delhi, 1990.
[16] R. H. Abaza, T. T. Blake, and E. I. Fisher, "Oxalate determination, analytical problem encountered with certain plant species". I. O., A.O.A.C.,Vol. 51, 1968, p.5
[17] A. Singh and N. Wadhwa, " A review on multiple potential of aroid: *Amorphophallus paeoniifolius, International Journal of Pharmaceutical Sciences Review and Research*, Vol. 24(1), 2013, pp. 55-60.
[18] L. Vamos-Vigyazo, " Poplyphenol oxidase and peroxidase in fruits and vegetables", *CRC Crit. Rev. Food Sci. Nutr*., Vol. 15, 1981, pp.49-127.
[19] H. Feng, Y. Yin, and J. Tang, "Microwave drying of food and agricultural material: basics and heat and mass transfer modeling", *Food Eng. Rev.,* Vol. 4, 2012, pp.89-106.
[20] G. Dadali, D. K. Apar, and B. Özbek, "Estimation of effective moisture diffusivity of okra for microwave drying", *Drying Technology: An International Journal*, Vol. 25(9), 2007, pp.1445-1450.

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